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THE NACA BALANCED-DIAPHRAGM DYNAMOMETER-TORQUE INDICATOR

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THE NACA BALANCED-DIAPHRAGM DYNAMOMETER-TORQUE INDICATOR

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SUMMARY

A balanced-diaphragm device for measuring dynamometer torque of single-cylinder or multicylinder engines is described. This device, which was developed for laboratory use, has proved to be accurate, reliable, and adaptable. Compressed air, automatically controlled, is used as the balancing and the transmitting fluid; thus, a simple method of obtaining torque measurement at a remote position is provided.

INTRODUCTION

The balanced-diaphragm torque indicator described in this report automatically balances the dynamometer force with air pressure. The measurement of the balancing air pressure indicates the force. It has been adapted for use with single-cylinder and multicylinder engines.

Torque meters of the balanced-piston type or of the diaphragm type in which the force applied to the piston or diaphragm is automatically balanced by a fluid pressure and its value is indicated at a remote position have been in use for a number of years. One of the first of such devices was the Bendemann hub dynamometer (reference 1). A further development is the currently used torque-measuring nose of Wright aircraft engines (reference 2) and of Pratt & Whitney aircraft engines (reference 3).

In 1941 members of the NACA laboratory staff experimented with and used a mercury-sealed piston for measuring dynamometer torque. In that device the force on the piston was balanced by compressed air supplied through a pilot valve. The air pressure under the piston was measured with a water manometer. The device proved to be very accurate, but its construction was complicated and its capacity limited.

The development of the balanced-diaphragm torque indicator described herein was carried out during 1942 and 1943 at the NACA Aircraft Engine Research Laboratory at Cleveland, Ohio.

DESCRIPTION AND DISCUSSION OF DESIGN VARIABLES

Requirements of a laboratory torque-measuring device. - The following characteristics are desired in a torque-measuring device:

1. A readable accuracy of ±0.5 percent over a force range from 1 to 10

2. A force reading indicated at a remote position and unaffected by temperature, barometric pressure, relative elevations of the diaphragm cell and the indicating instrument, vibration, or a vibrating load

3. A construction sufficiently rugged that the calibration will remain constant over long periods of time

4. A straight-line calibration curve that does not differ as load is applied from the calibration as load is removed

A schematic layout of the device for measuring dynamometer torque designed to meet the foregoing requirements is shown in figure 1. The dynamometer-torque load on the diaphragm is balanced by air pressure introduced through a pilot valve. Laboratory service air passes through filters and a pressure-reducing valve to the pilot valve that moves with the diaphragm and admits compressed air when the torque increases and permits escape of the air when the torque decreases. The diaphragm thus remains balanced in practically the same position under all conditions of load, but loading is restricted to one direction. The torque measurement is obtained from a manometer reading that indicates the air pressure under the diaphragm. Figure 2 is a sketch of a section through the diaphragm cell and the pilot valve shown in figure 1. Actual torque-measuring installations on 1500-, 1000-, and 300-horsepower dynamometers are shown in figures 3, 4, and 5, respectively.

Diaphragm design. - Because the choice of diaphragm size is determined by the load and the desired manometer pressure, a number of designs are possible. Because the flexibility of the diaphragm varies inversely as the thickness, the diaphragm should be made as thin as strength requirements will permit. The diaphragms used in the device described in this report were of 1/32-inch neoprene-impregnated fabric. Air pressures as high as 25 pounds per square inch have been used on this material.

Because the balancing force on the diaphragm depends on the diaphragm area, and because the force resisting the free movement of the diaphragm is governed by the perimeter of the diaphragm, the sensitivity is increased by using a diaphragm of large diameter. The effective area of flexible diaphragms is usually taken as the area computed from the average diameter of the flexible part. The difference between the diameter of the diaphragm-loading disk and the outside diameter of the diaphragm should be relatively small. For example, the difference between the diameter of the loading disk (9 in.) and the diameter of the diaphragm ($10\frac{1}{4}$ in.) of the unit in figure 2 is $1\frac{1}{4}$ inches.

In the initial adjustment of the device the neutral position of the diaphragm should coincide with the equilibrium position of the pilot valve. By neutral position is meant the position in which the supported areas of the diaphragm are in the same plane. Inasmuch as the loading disk is continually balanced at the neutral position, the effect of diaphragm stiffness is practically eliminated. For the device shown in figure 2 the maximum movement of the diaphragm when changing load is less than 0.030 inch. For the unit shown in figure 6 this movement is less than 0.015 inch.

Pilot valve. - The pilot or balancing valve (fig. 2) is a commercially available piston-ported spool valve. Another type of pilot valve that has been used with equally good results is the double-ported poppet valve (fig. 6). The poppet-valve type requires no lapped surfaces and is somewhat less dependent on the method of attaching the actuating link. The spool-valve type is, however, more adaptable. In both the poppet and spool types of valve it is essential that the intake and discharge ports open with a throttling effect in order to avoid excessive movement of the diaphragm and possible hunting.

Torque-indicating instrument. - Because the over-all precision of torque measurement can be no more accurate than the precision of reading the indicating scale, the scale must be of sufficient length to insure the desired accuracy. For accurate measurement of dynamometer torque in engine testing, an indicator movement of not less than 1/10 inch per unit brake mean effective pressure has proved satisfactory provided that observations can be made at close range. This requirement makes it necessary to have an indicator with a scale length of 30 or 40 inches; thus a manometer is an ideal instrument for this purpose. In order to eliminate use of a single manometer with a scale more than 40 inches in length, well-type manometers can be placed in parallel. In this case the tubes of all manometers are extended upward to cover the entire range, and the scale of the first manometer indicates the first 40 inches. For each successive manometer the well is lowered so that the scale indicates the successive 40-inch interval.

The use of air as the transmitting medium makes it convenient to locate the manometer at any desired elevation with respect to the diaphragm without the necessity for a correction in pressure head. The use of air for transmission, furthermore, makes it readily possible to connect two or more remotely located indicating manometers in parallel and, where the tests require a complete time history of the torque, to provide a chart recorder.

Capacity range of dynamometer-torque measurement. - In dynamometer testing of engines of different size, provision must be made for measuring an extremely wide range of torque. In the balanced-diaphragm type of force-measuring device this requirement can be met by the following methods:

1. Changing the density of the fluid in the indicating manometer

2. Providing a long tube manometer or a pressure gage

3. Loading the dynamometer with fixed weights to bring the readings within the desired range

4. Changing the force on the diaphragm by changing the mechanical advantage

Method 4 is employed in the installations shown in figures 5 and 7 by moving the diaphragm along the beam.

The choice of the foregoing methods is largely a matter of the conditions of use. In some cases it may be desirable to guide the diaphragm by means of a beam. (See fig. 5.) In other cases direct application of the force to the diaphragm may be just as satisfactory and is much simpler.

Reversed operation. - Reversed operation has been obtained by the use of a reversing-link mechanism, as shown in figures 5 and 7. Another method is to employ a diaphragm for each direction of rotation.

For use in engine testing, where the measurement of engine-friction torque in one direction is only 10 to 20 percent of the torque in the opposite direction, a very satisfactory and simple arrangement has been to unbalance the dynamometer to the extent of the maximum friction torque so that a unidirectional force is incident on the diaphragm regardless of the direction of engine torque. The disadvantage of this arrangement is that the lower fifth of the manometer is used for reversed-torque indication and the manometer tube must be lengthened for a given torque.

Double-acting operation. - The device can be made double acting by using a small diaphragm seal around the stem and by a suitable arrangement of pilot valve and connections to the air chamber above the diaphragm. During reversed operation the dynamometer force puts the stem in tension and is resisted by air pressure above the diaphragm. The double-ported pilot valve has provisions for operating both sides of the diaphragm and with suitable tubing connects air pressure to either side and opens the opposite side to the atmosphere. Similar reversed action can be obtained by connecting the under side of the diaphragm to a vacuum source through the pilot valve. When the force on the diaphragm is downward, compressed air is the resistant force and, when the force on the diaphragm is upward, atmospheric pressure is the resistant force.

RESULTS AND DISCUSSION

Accuracy. - The inherent accuracy of torque-measuring devices is generally indicated by how often the calibration changes and whether the calibration as load is applied differs from the calibration as load is removed. A calibration curve for the unit pictured in figure 3 is presented in figure 8. In both this calibration curve and the calibration curve in figure 9 the readings with an increasing load are the same as the readings with a decreasing load.

A straight-line calibration curve, as plotted in figures 8 and 9, is of considerable advantage and leads to general over-all accuracy of test results. The slope of the line can be incorporated for convenient use in various expressions relating to engine performance. It has been possible to obtain a straight-line calibration curve except for diaphragm pressures of less than 8 inches of water. In this range of pressure the points on the calibration curve have frequently been observed to fall below the characteristic straight-line curve. In such cases the deviation from a straight line can be practically eliminated by preloading the dynamometer to about 10 inches of water. The 10-inch point on the manometer then becomes the arbitrary zero point; the engine-torque reading is indicated on the scale above 10 and the friction-torque reading is indicated on the scale below 10.

Experience with the balanced-diaphragm torque indicator has shown good stability of calibration. A change in the relationship of pilot valve and diaphragm, however, requires a new calibration unless care is taken to accurately reproduce the initial setting. This setting is accomplished on the apparatus (figs. 5 and 7) by adjusting the screw at the center of the diaphragm until the 5-inch gage pin shown in figure 5 just slides under the beam. This procedure is not necessary in order to obtain an accurate calibration, but it does permit reproduction of a calibration if the adjustments become altered. Reproducibility of calibrations has been found to be practically independent of vibration and of a vibrating load.

Stability of operation. - Self-energized oscillation, or hunting, of the diaphragm has been observed during some conditions of operation. This condition has been encountered only with diaphragm assemblies that have been operated with pressures that require mercury manometers. Hunting was eliminated by placing a restriction (needle valve) between the pilot valve and the diaphragm. (See fig. 1.) No trouble has been experienced with hunting in the water-manometer range provided that low air pressures are supplied to the pilot valve. In general, the air pressure should be maintained at a value just sufficient for the fully loaded condition. Experiments have shown that a considerable variation in the supplied air pressure has no appreciable effect on the calibration.

CONCLUSIONS

Experience with the force-measuring device described in this report permits the following conclusions:

1. The accuracy of measurement is satisfactory. The effects of temperature, barometric pressure, and vibration on the reproducibility of the calibration are negligible.

2. The use of compressed air as the transmitting fluid between the diaphragm cell and the manometer is satisfactory and permits flexibility in the location of the indicating instrument.

3. Preloading the diaphragm provides a simple and accurate method of providing for reversed-torque measurements.

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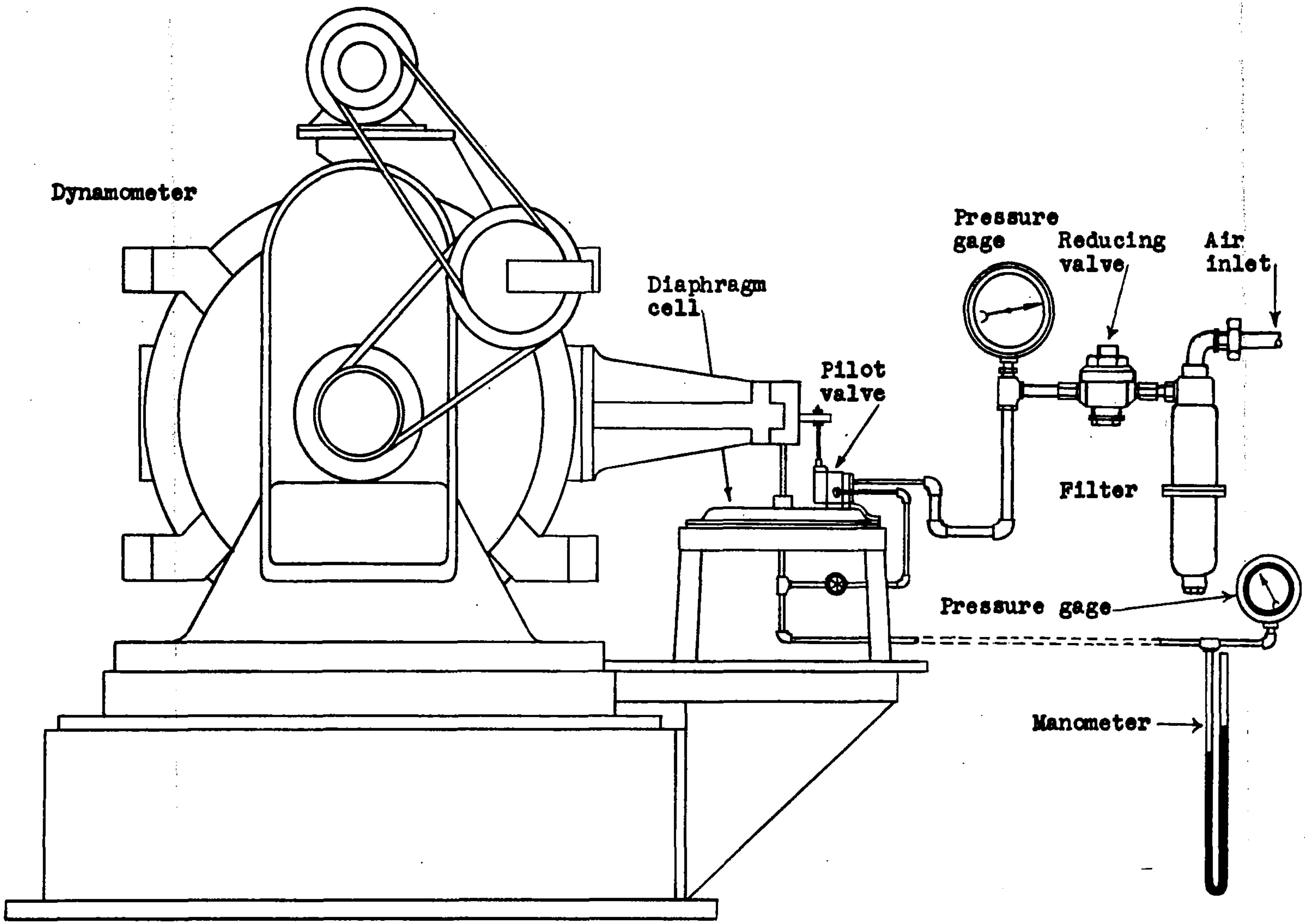

Figure 1.- Schematic diagram of dynamometer-torque indicator.

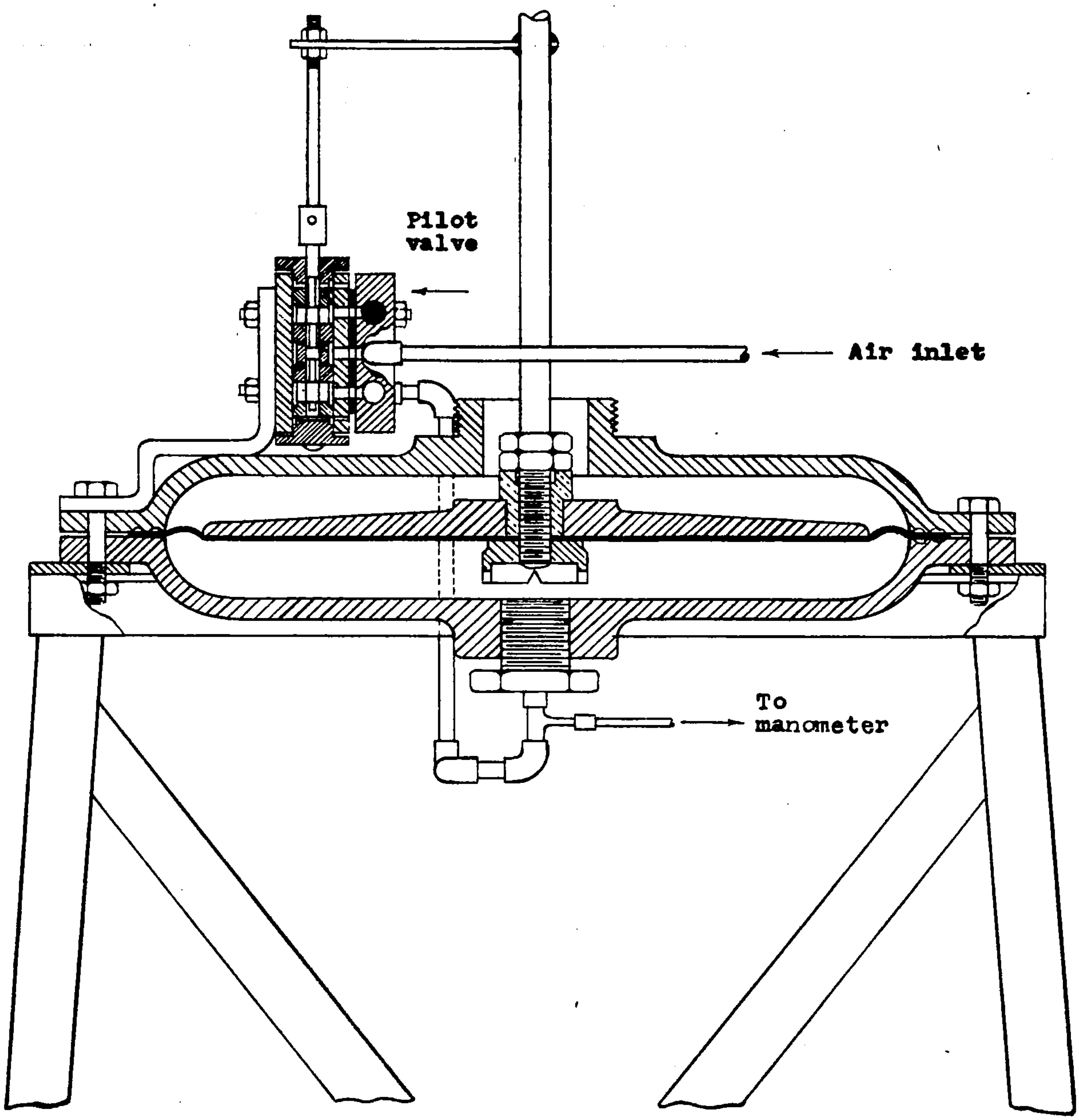

Figure 2.- Cross section of diaphragm cell and piston-type pilot valve.

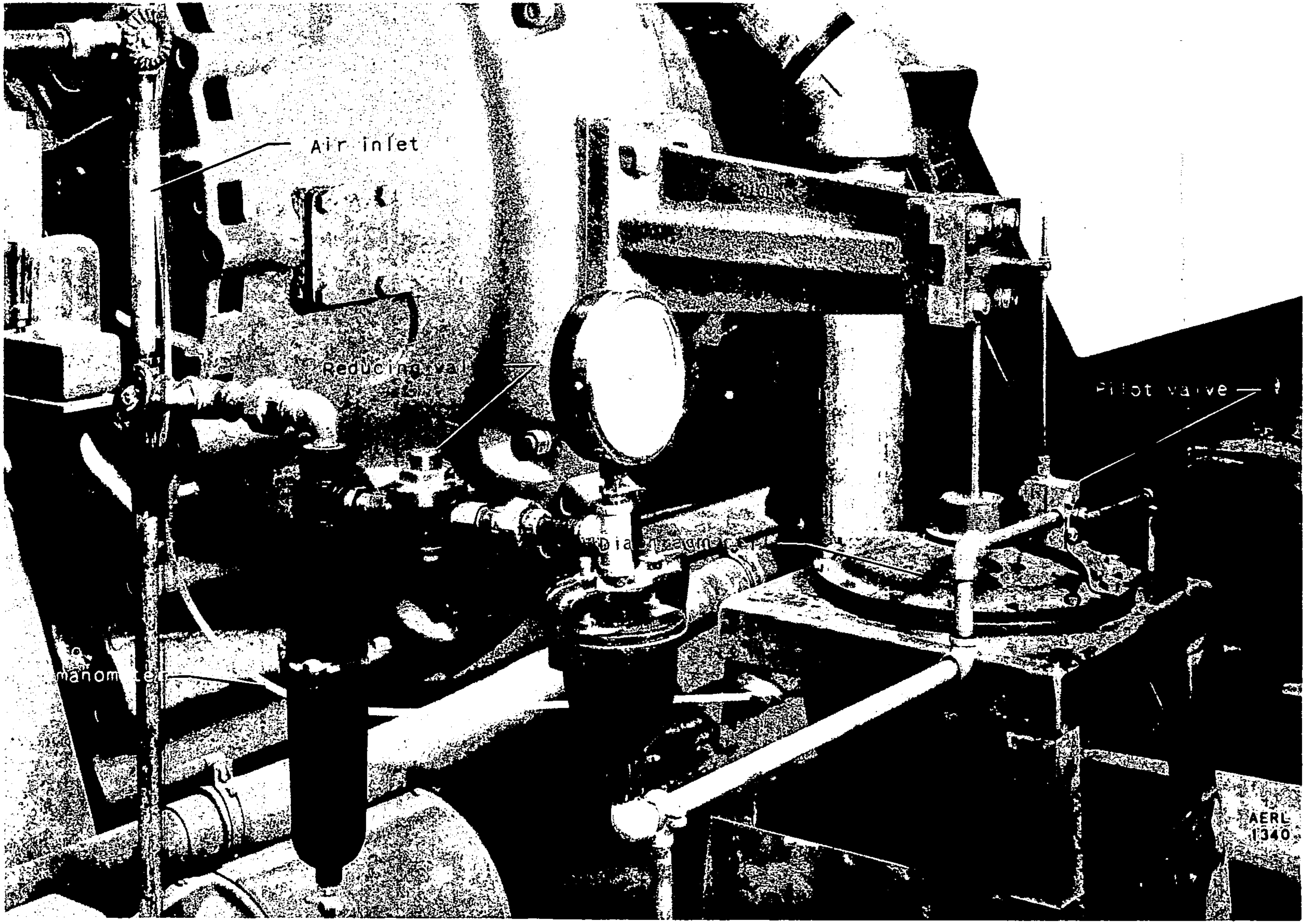

Figure 3.- Installation of torque indicator for 1500-horsepower dynamometer.

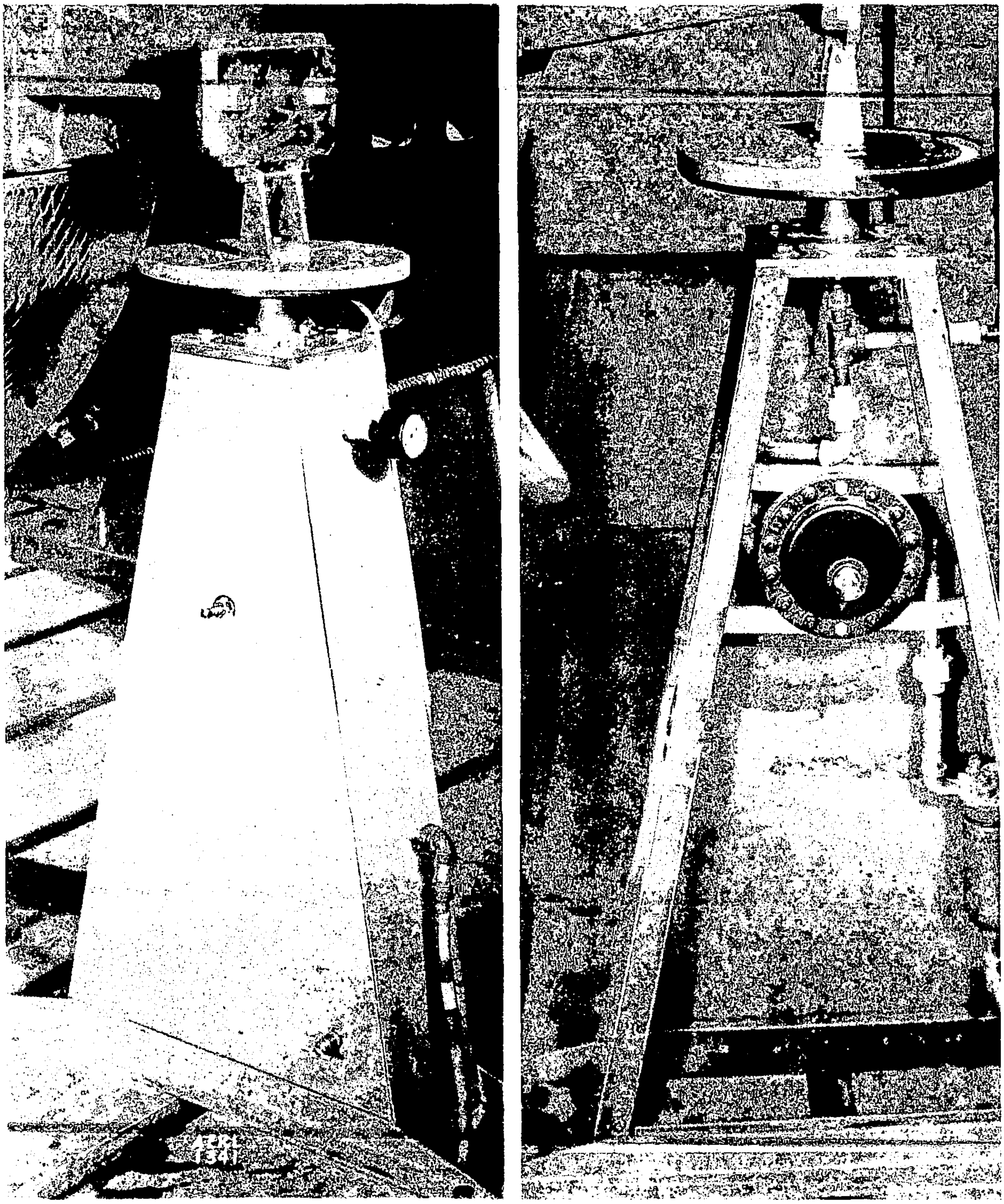

Figure 4.- Installation of torque indicator for 1000-horsepower dynamometer.

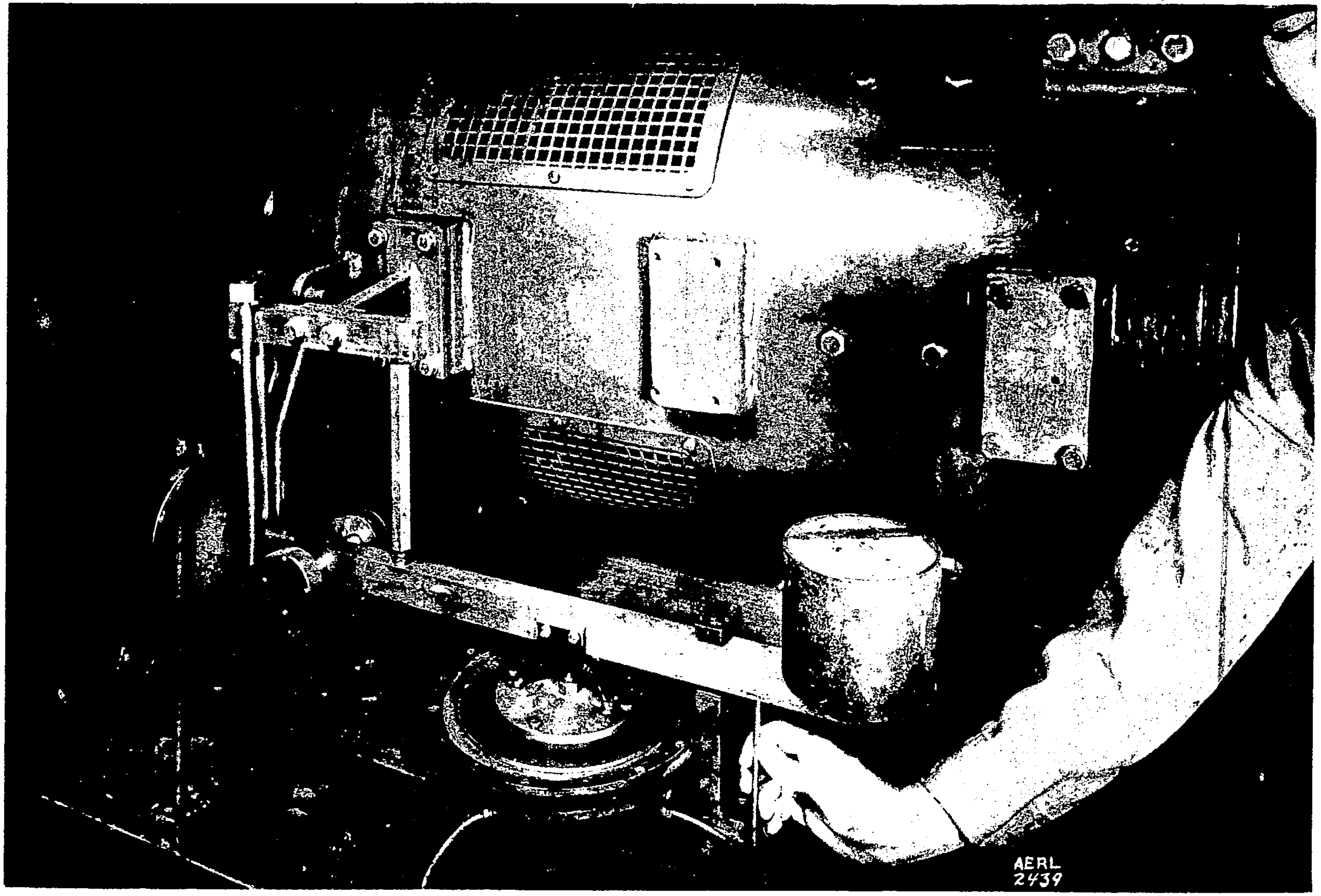

Figure 5.- Installation of torque indicator (with reversing-link mechanism) for 300-horsepower dynamometer.

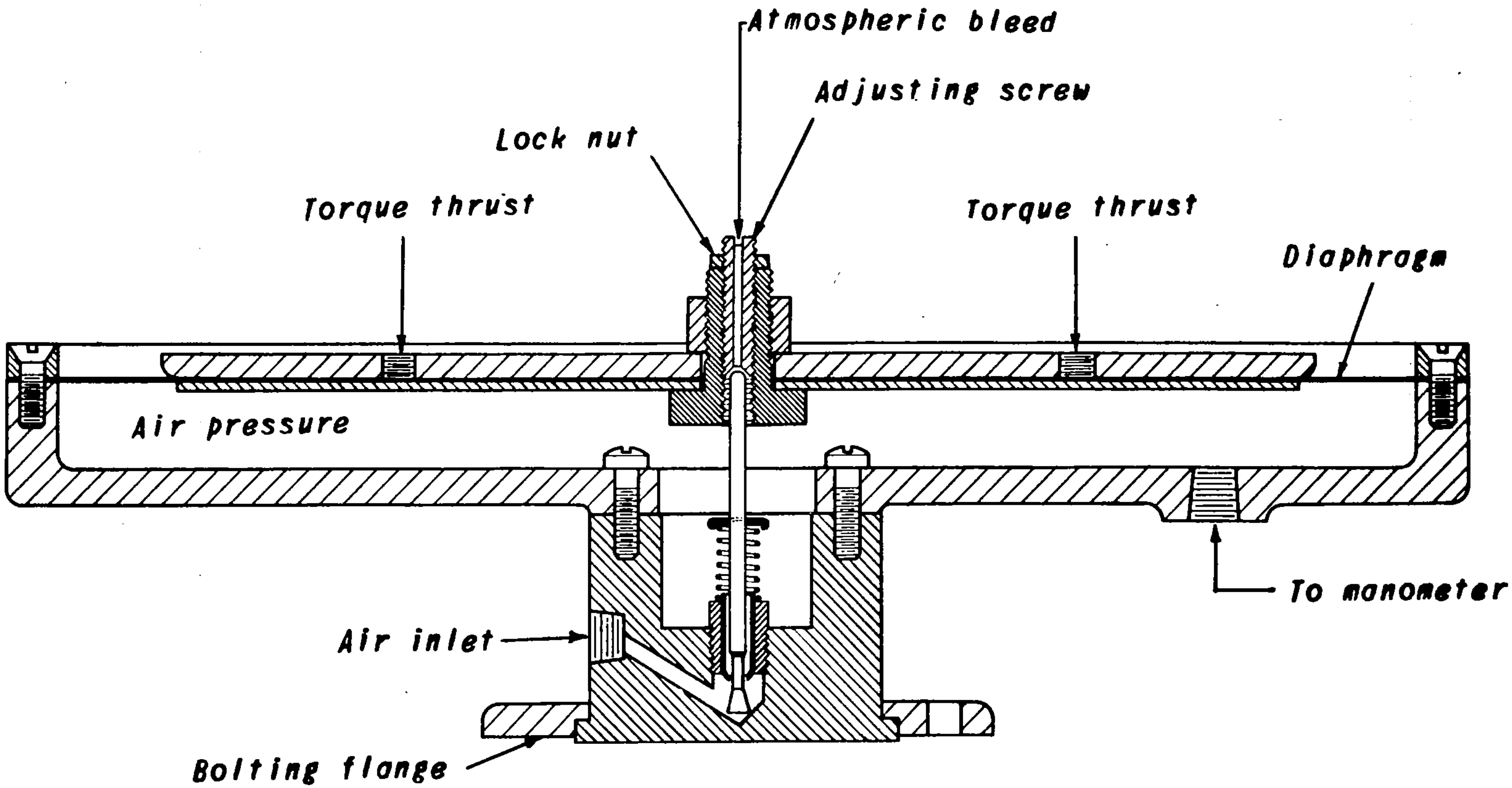

Figure 6. - Cross section of diapnragm cell and poppet-type pilot valve.

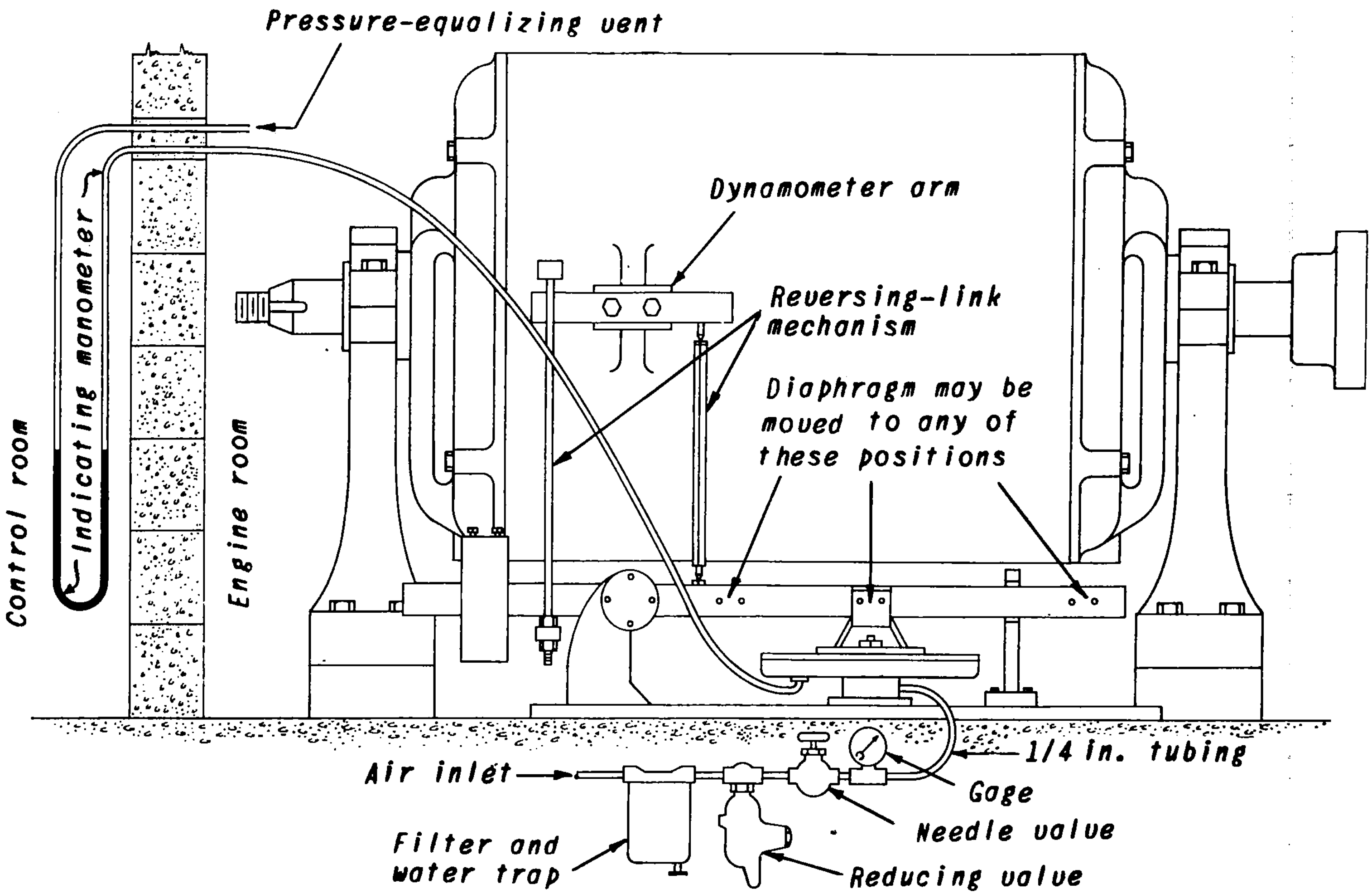

Figure 7. - Schematic diagram of dynamometer-torque indicator with reversing-link mechanism.

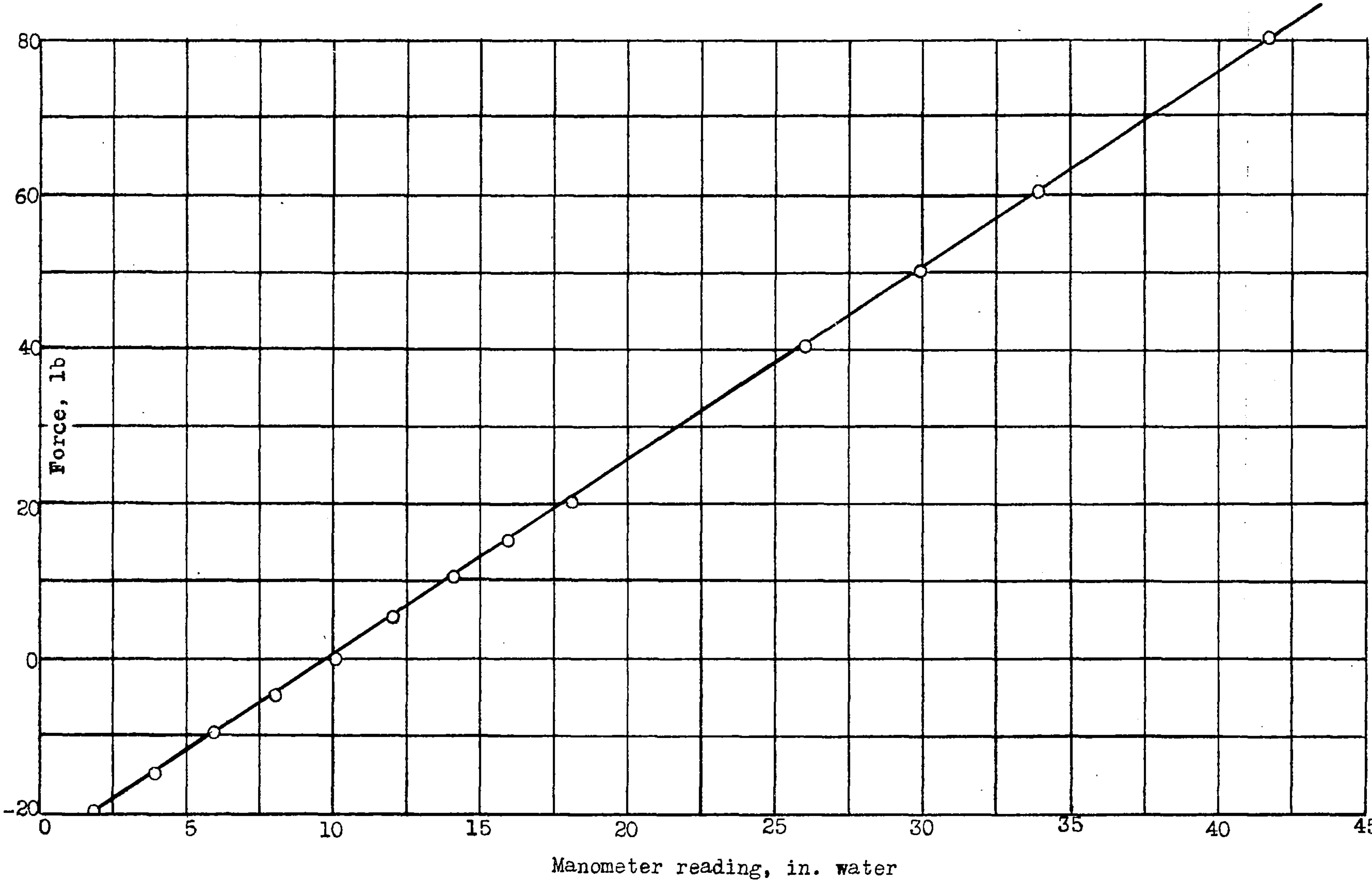

Figure 9.- Calibration of torque indicator for 300-horsepower dynamometer.